

Development of the SAMEX Vector Magnetograph at the Marshall Space Flight Center

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Abstract

A breadboard design to prove the operational feasibility of SAMEX Vector Magnetograph is being developed at Marshall Space Flight Center (MSFC). Although the breadboard design will not include all of the elements of the original design concept, critical elements such as the large detector array and the high resolution polarimeter will be important parts of the breadboard design to study the data analysis and compression techniques that will be needed in a SAMEX instrument, to study the calibration techniques for systematic errors in the polarimeter, and to obtain high resolution vector magnetograms during the next solar maximum. Although the SAMEX polarimeter is not optimum for a groundbased patrol instrument, the design concept can be confirmed with groundbased measurements and direct comparisons with the existing MSFC vector magnetograph. The extension of the scientific objectives for this breadboard design is possible if a tunable filter can be acquired.

The SAMEX Vector Magnetograph study was supported by the Air Force Geophysical Laboratory through its Solar Research Branch of the Space Physics Division. The development of the SAMEX detector system is being supported by a NASA Small Business Innovative Research grant to BGB, Inc., Huntsville, Alabama.

Scientific Objectives of the SAMEX Vector Magnetograph

- + To observe the formation and configuration of non-potential fields in photospheric active regions
- + To quantify the non-potential characteristics of these fields (e.g., angular shear, electric currents) in flaring and non-flaring regions
- + To quantify the free magnetic energy and the force-free nature of active-region fields as they develop and evolve
- + To determine what factors lead to the destabilization of the fields and the eruption of flares

Instrumental requirements to meet Scientific Objectives

- + Temporal resolution of a few minutes
- + Field of View to contain a typical active region
- + Spatial resolution of at least 0.5"
- + Polarization resolution of at least $10E-4$
- + Spectral resolution of approximately $1/8$ Angstrom

The diagram illustrates the architecture of the Solar Wind Magnetograph (SWM) system, showing the flow of data from the telescope to the final telemetry output.

Input and Initial Processing:

- Spatial Resolution:** 0.5" (360 km) sub-granular.
- Aperture:** 30 cm.
- Obscuration ratio:** 0.3.
- efficiency factor ϵ :** 0.06.
- Field of View:** Active Region - 4.3" x 8.5" field topology.
- Array:** 1024 x 2048.
- Masked:** Calibration.
- Solar Rotation:** Temporal Resolution: ~5 min/magnetogram <granule lifetime.

Data Flow and Processing:

- Radially Symmetric Cassegrain Telescope** (labeled 1) feeds into the **Aperture** and **Field of View** blocks.
- Obscuration ratio** and **efficiency factor ϵ** are inputs to the **Exposure Time** calculation.
- Exposure Time** is calculated as $T = \left(\frac{S.H.C.W.}{F.A.D.\lambda.\epsilon} \right)$ with a value of 370 msec.
- Exposure Time** feeds into the **Multiple Ports (4)** block.
- Multiple Ports (4)** feeds into the **2048 x 2048 Solid State Detector (CCD)**.
- 2048 x 2048 Solid State Detector (CCD)** feeds into the **1.5 Gb 5 magnetograms** block.
- 1.5 Gb 5 magnetograms** feeds into the **On Board Memory 1.5 Gb** block.
- On Board Memory 1.5 Gb** feeds into the **Single Stokes Measurement 18/83 sec** block.
- Single Stokes Measurement 18/83 sec** feeds into the **4.5 measurements** block.
- 4.5 measurements** feeds into the **Four Stokes Parameters** block.
- Four Stokes Parameters** feeds into the **Polarization** block.
- Polarization** block includes the formula $B_1 - P_V, B_1 - P_Q, 10^{-4}$.
- Polarization** feeds into the **Spectral Filter** block.
- Spectral Filter** block includes the specification 120 mA FWHM / 1 mA.
- Spectral Filter** feeds into the **Acquisition Time .37 sec** block.
- Acquisition Time .37 sec** feeds into the **Data Rate 0.56 Mbps** block.
- Data Rate 0.56 Mbps** feeds into the **Duty Cycle** block.
- Duty Cycle** block includes the specifications -1 hr / magnetogram and ~5 min / magnetogram.
- Duty Cycle** feeds into the **TDRSS Telemetry** block.
- TDRSS Telemetry** block includes the specifications 30 Kbps / continuous and 3 Mbps / intermit.

Additional Information:

- 50/225 enhancements** feeds into the **Acquisition Time .37 sec** block.
- 12 bit A/D -0.3 usec/pixel** feeds into the **20 bit storage** block.
- 20 bit storage** feeds into the **Acquisition Time .37 sec** block.
- 10 bit** feeds into the **2048 x 2048 Solid State Detector (CCD)**.
- S/N ~ 1000** feeds into the **2048 x 2048 Solid State Detector (CCD)**.
- S/N ~ 10⁻⁴** feeds into the **Acquisition Time .37 sec** block.

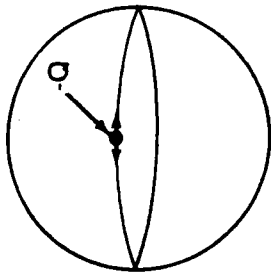
Figure 11. The overall interrelations of the SAMEX magnetograph requirements. This diagram shows how the design specifications for spatial resolution, field of view, temporal resolution, and magnetic sensitivity are interrelated with each other and produce requirements on the magnetograph instrument, onboard computers, and spacecraft systems. To satisfy most of these requirements, an optimum sense requires many different trade-offs. The details of these relationships are described in the text.

Reasons for selecting a rotating polarizer as the active element in the polarimeter

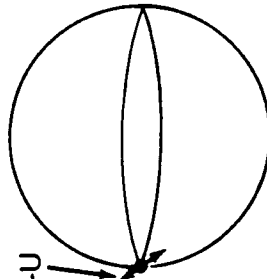
- + The transverse field (linear polarization) is more difficult to measure (the longitudinal field is related to the circular polarization), therefore the polarimeter should be optimized for the linear polarization measurement.
- + The removal of retarders in the linear polarization measurement eliminates circular crosstalk (which is the stronger signal) and improves the polarization resolution.
- + Using redundant measurements, systematic errors in the remaining retarders (the rotating quarterwave plate following the analyzer and the fixed quarterwave used to measure the circular polarization) can be corrected for.

Table 1. Sequence of measurements using a rotating polarimeter and fixed quarterwave plate

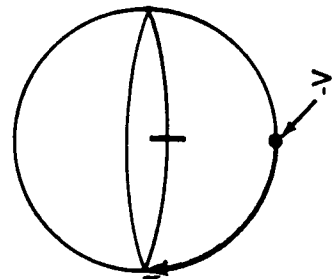
Angle of polarizer	Intensity measurement	
	Wave plate out	Wave plate in
0°	$I + Q$	$I + Q$
45°	$I + U$	$I + V$
90°	$I - Q$	$I - Q$
135°	$I - U$	$I - V$
180°	$I + Q$	$I + Q$
225°	$I + U$	$I + V$
270°	$I - Q$	$I - Q$
315°	$I - U$	$I - V$



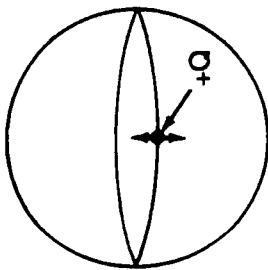
I-Q
ANALYZER
@ 90°



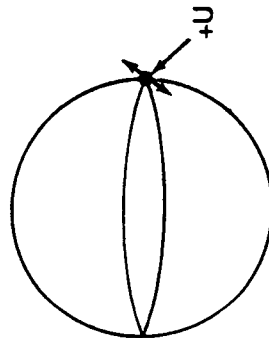
I-U
ANALYZER
@ -45°



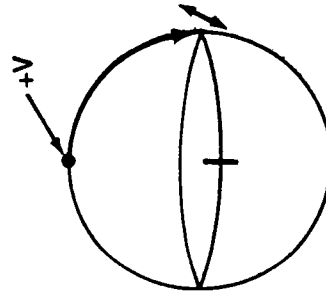
I-V
λ/4 PLATE @ 0°
ANALYZER
@ -45°



I+Q
ANALYZER
@ 0°

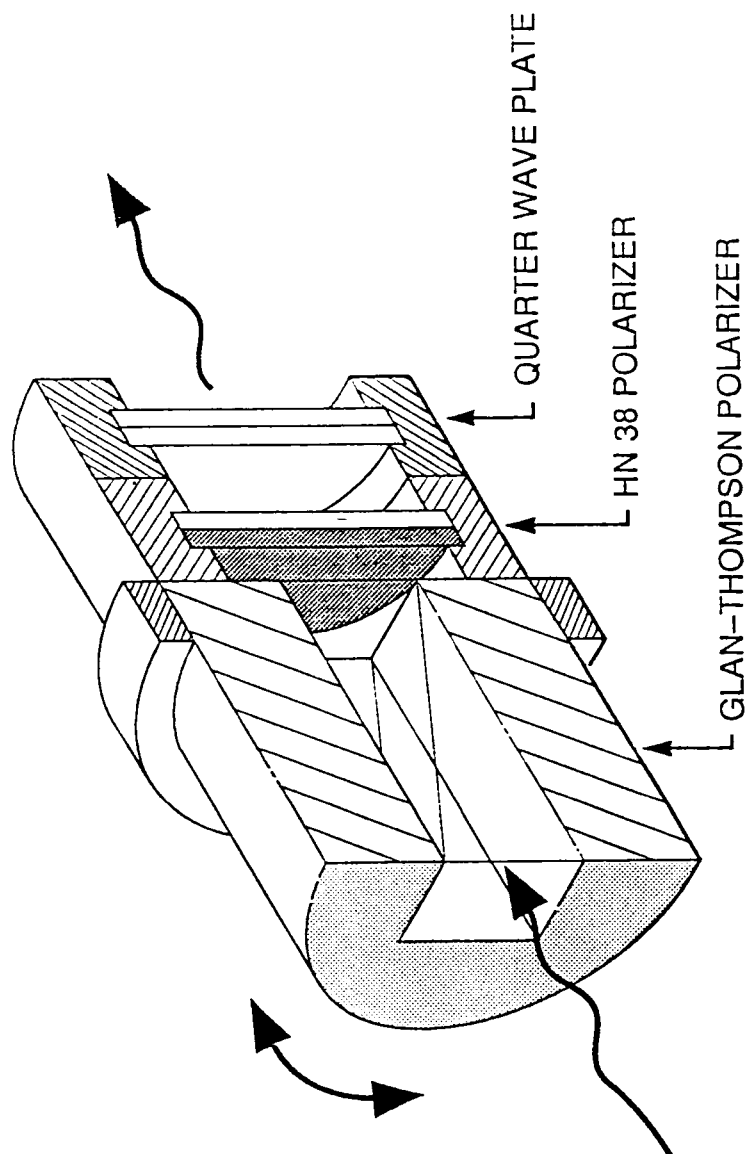


I+U
ANALYZER
@ 45°

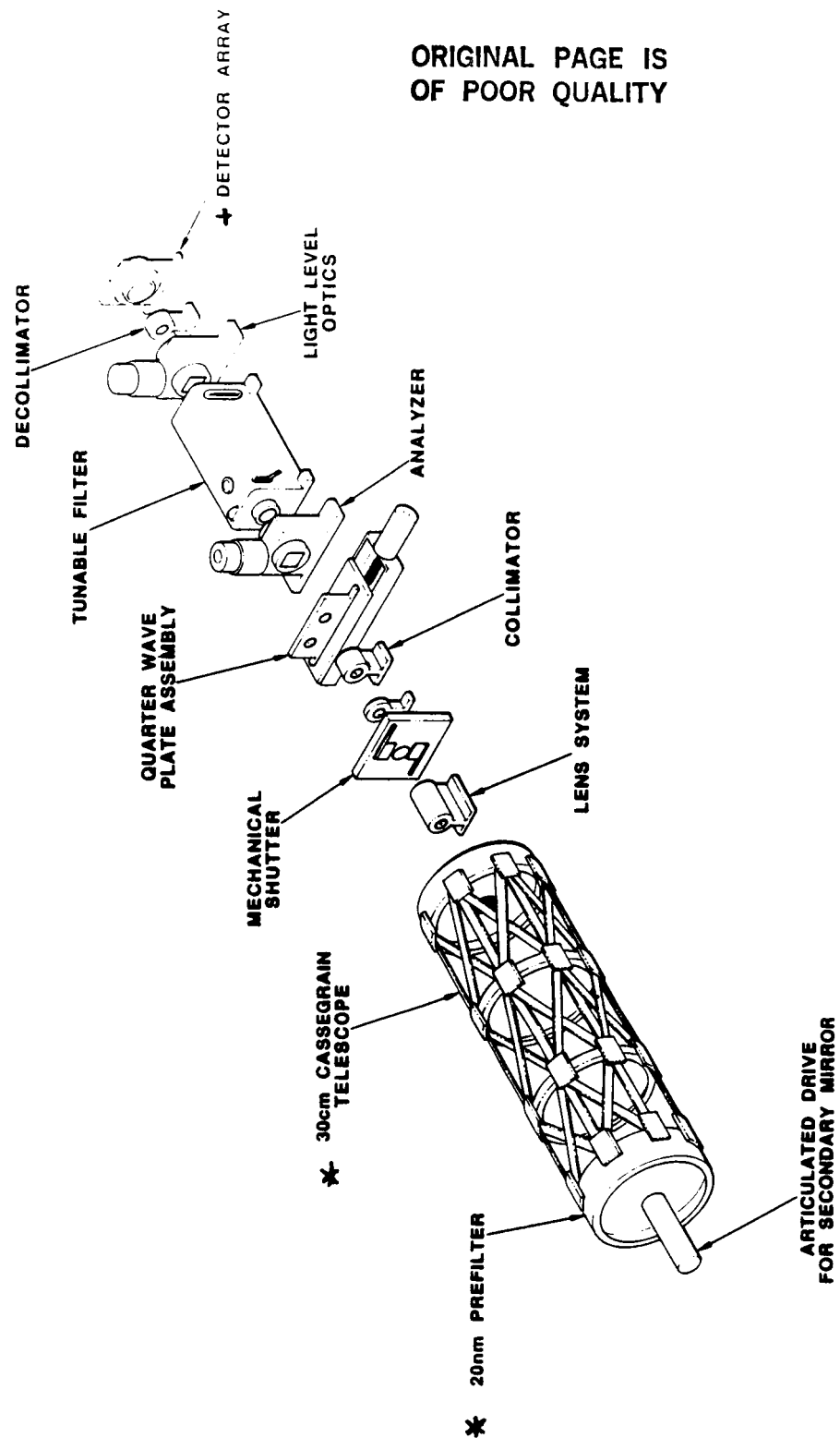


I+V
λ/4 PLATE @ 0°
ANALYZER
@ 45°

Rotating Analyzer



THE SYSTEM CONFIGURATION FOR THE SOLAR VECTOR MAGNETOGRAPH



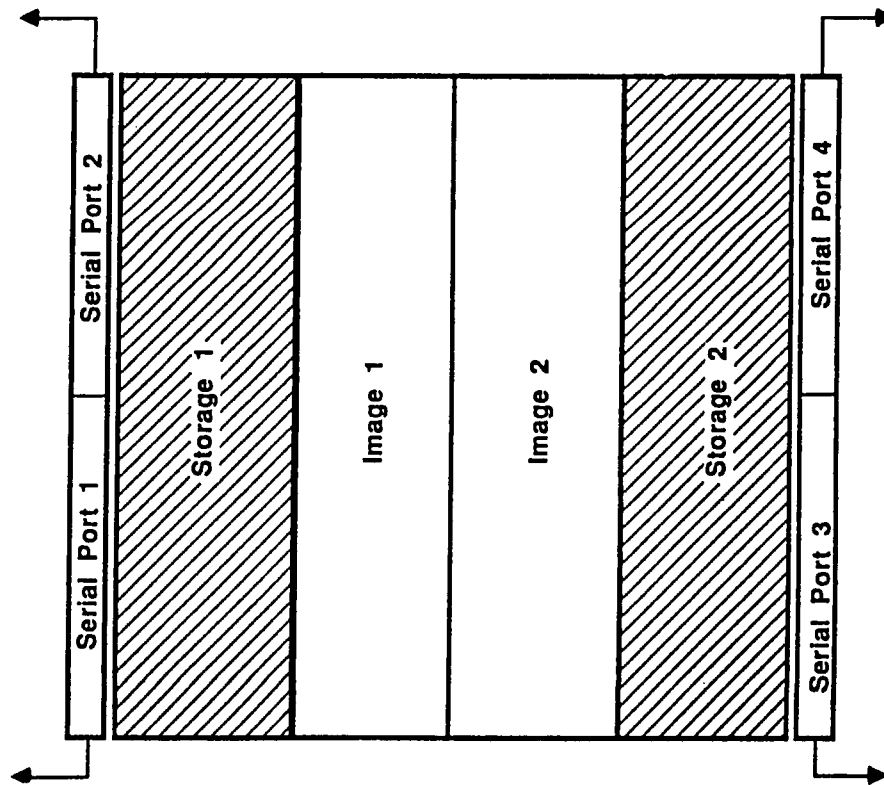
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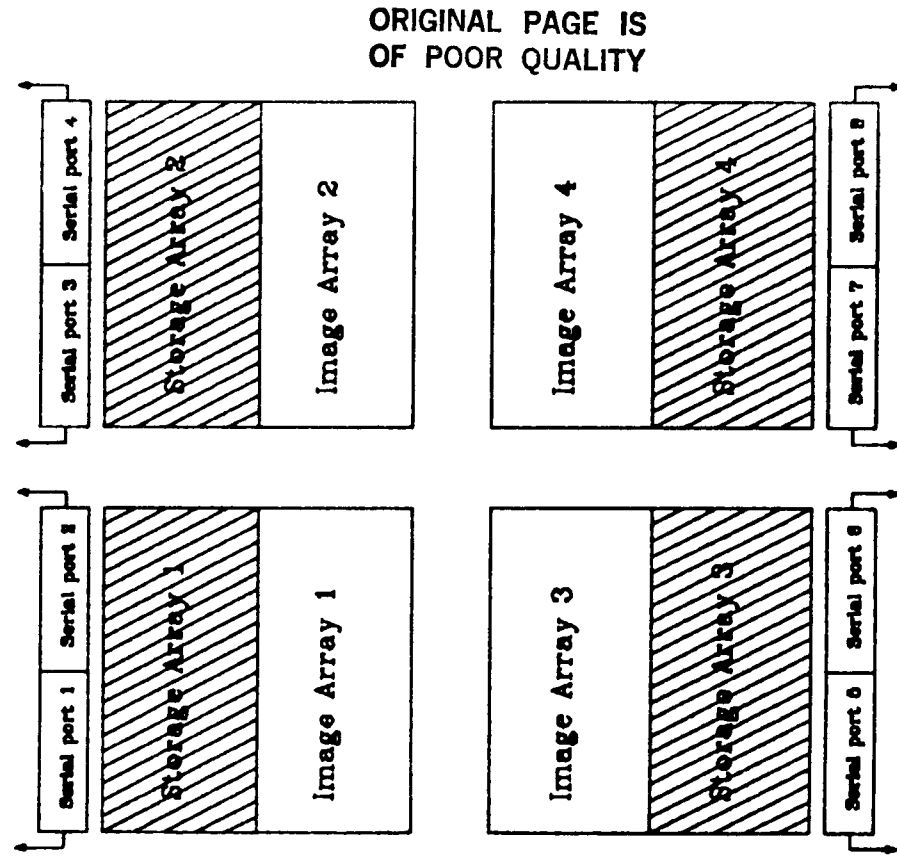
	Proposed SAMEX detector system	Preliminary breadboard design
Manufacturer:	Tektronix	Thomson
Array size:	2048 x 2048	4 (1024 x 1024)
Pixel size:	27 microns	19 microns
Well size:	750K electrons	250K electrons
Quantum Efficiency:	45 %	45 %
Proposed readout rate	4.8 Megapixels/sec.	9.6 Megapixels/sec.

There are 4 serial ports on each Thomson CCD. The camera controller will be designed for flexibility so that it can handle CCD's developed in the future. The 2 port design (8 total) is required to match the smaller well size of the Thomson sensor with the S/N and time resolution requirements that satisfy the scientific objectives.

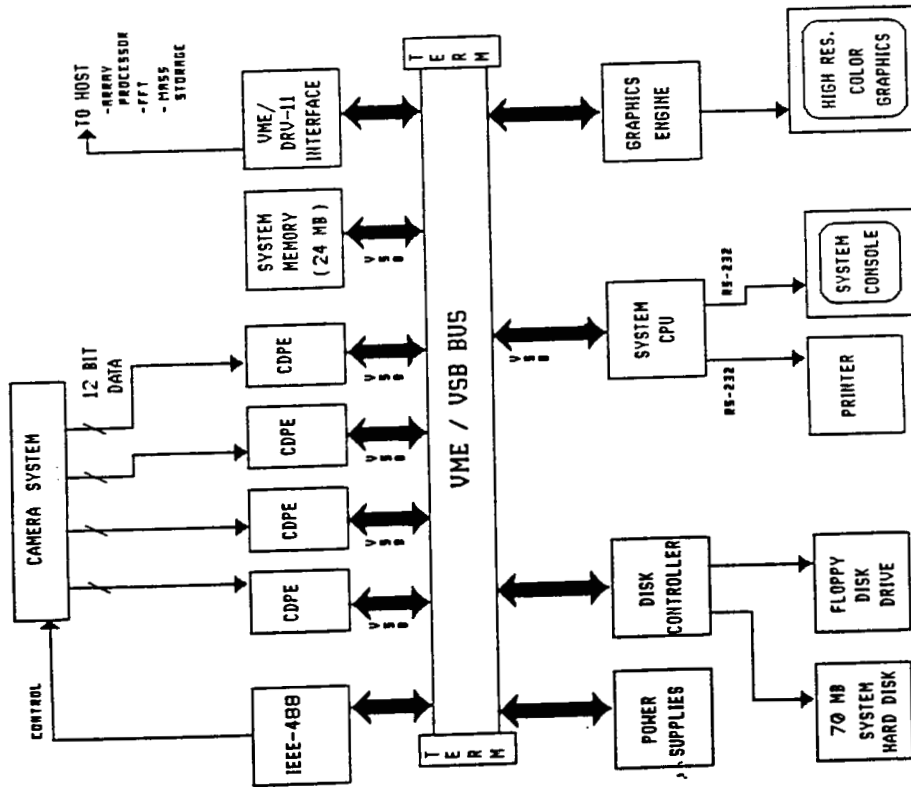
Proposed SAMEX detector system



Preliminary breadboard design



Preliminary Design of the Solar Vector Magnetograph Data Acquisition System



Preliminary design produced by Ralph Kimball of Echotek Inc.